LIVE FIRE OVERVIEW

The Live Fire Test and Evaluation (LFT&E) Program was enacted into law by Congress in FY86. From its inception, the program has required realistic survivability and lethality testing on platforms and weapons to assure that our major systems perform as expected and that our combat forces are protected. The law has proven both enduring and flexible, and permits test realism to be balanced against cost and practicality.

Fiscal Year 2000 marked the sixth year since the Federal Acquisition Streamlining Act mandated that the LFT&E Program should become an integral part of the DOT&E mission. The integration of the LFT&E Program into the DOT&E mission has enabled DOT&E to take a more balanced look at weapon system effectiveness, suitability, and survivability. LFT&E is primarily driven by the physics of failure mechanisms, and often requires destructive testing under conditions not possible in OT&E. Conversely, OT&E provides LFT&E with insights into the operational conditions under which LFT&E results should be evaluated.

LFT&E addresses both the survivability of our platforms (e.g. armored vehicles, aircraft, ships, and their crews) and the lethality of our weapons systems (e.g. munitions and missiles). Fiscal Year 2000 saw the number of programs under DOT&E LFT&E oversight at an all-time high, rising to well over 80 programs by the end of FY00. These programs are nearly evenly divided between weapons platforms assessing their survivability (fixed and rotary wing aircraft, ships, and land combat vehicles) and weapons assessing their lethality (strategic and tactical missile systems, precision weapons, bombs, torpedoes, and projectiles, etc.). In fact, this year alone, a total of ten systems completed their LFT&E programs and sent their reports to Congress, more than in any year in the 14-year history of the program.

LFT&E supports the warfighter. The question asked without exception by every warfighter is, "Will my weapons platform take a hit from the threat and still allow me to complete my mission and get home?" It does not matter if the platform is a tank, fighter, bomber, ground or air troop transport, helicopter, submarine, frigate, or aircraft carrier; the question is still the same. The concern is, "Is my platform survivable in combat?" The purpose of Live Fire is to reduce the risk of casualties and concern in the minds of all Commanders as they enter harm's way. The U.S. Congress addressed these concerns when they enacted Section 2366, Title 10, U.S. Code, *"Major systems and munitions programs; survivability testing and lethality testing required before full scale production."*

Platform survivability must be built into each weapon system as early as possible in the acquisition process. It begins at the component-level initial design stage and extends throughout the entire system design development process, from sub-systems to assemblies, to systems, to full systems and finally to full-up, system-level. At the full-up, system-level, the weapon system is fully configured for combat with all sub-systems operational and powered on.

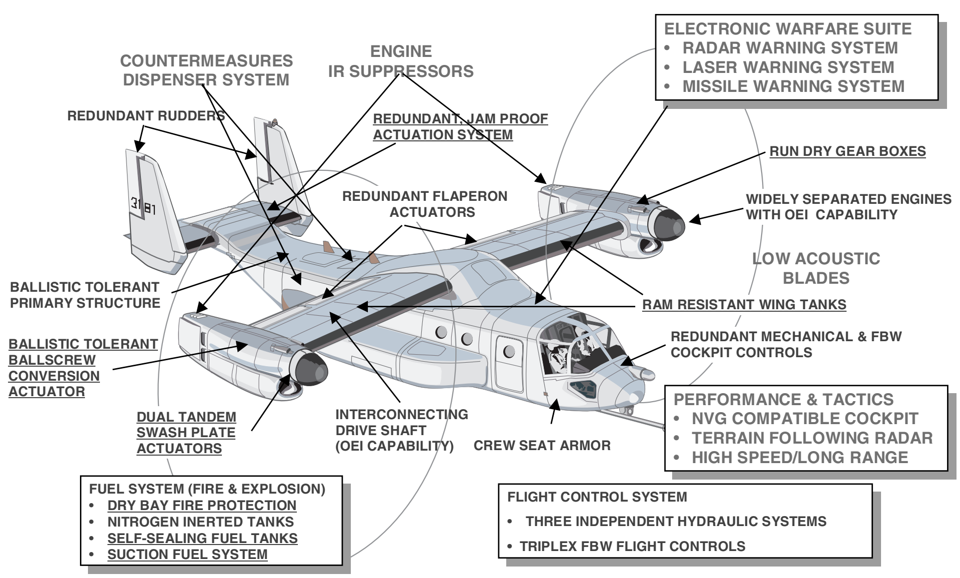
REAL LIFE EXAMPLES OF LIVE FIRE IN ACTION

Occasionally, the question gets raised as to what the value added of testing really is. In recent years, there have been a number of specific examples that demonstrate major positive impact, not only in making system designs more survivable and lethal but also by providing benefits in tactics, doctrine, and even battle damage repair procedures. I would like to illustrate with two current examples, the V-22 Osprey tilt-rotor aircraft and the DDG 51 AEGIS Class ship.

V-22 LFT&E

The V-22 was conceived as a combat assault aircraft designed to address the issue of rapid ship-to-shore movement and embassy rescue missions. The program started component-level vulnerability testing in 1984, prior to the passage of the 1986 Live Fire law, at which time it was placed on Live Fire Test (LFT) oversight. The V-22 employed the revolutionary design concept of a composite aircraft capable of converting between level flight and hover modes. Because of this new design concept, we encountered many new vulnerability questions. To address these questions, a series of Live Fire tests were conducted at the China Lake Naval Weapons Station's Survivability Laboratory. As design improvements were identified by these Live Fire tests, the weapons platform components were re-designed to allow for continued weapon system performance even if degraded from a threat impact.

THE V-22 SURVIVABILITY BALANCE
"SUSCEPTIBILITY & VULNERABILITY" REDUCTION
DESIGN FEATURES



The diagram of the V-22 depicts some of the specific design changes that reduce V-22 susceptibility and vulnerability. These changes resulted in reducing both susceptibility to being hit (in orange) and reducing the V-22's vulnerability when hit (in blue) by an expected threat system. The changes made hits to the rotor blades more survivable (approximately 1/3 of the total presented area of the aircraft), added several automatic fire suppression systems in case of hits in the fuel cells, added separation and redundancy to critical hydraulics systems, and provided special gear boxes that continue to function a full 30 minutes after losing their lubrication. The entire V-22 LFT&E program was completed at a cost of less than ¼ of 1 percent of the total cost of the program. Furthermore, the pre-test predictions required prior to every Live Fire Test, served to help calibrate the aircraft Modeling and Simulation (M&S) capabilities of the DoD. This is certainly a good news story.

DDG 51 FLIGHT I AEGIS LFT&E

Some have asked, "How can you do a live fire test program on a billion dollar ship? The answer is "carefully," but you must nonetheless do it. This leads me to the DDG 51 AEGIS Class Ship, another example of how LFT&E can and has had a very positive impact on platform design and crew training.

The ship was first identified as an LFT&E oversight program in 1987, shortly after LFT legislation was passed. We recognized early on that firing at the entire ship, combat-loaded, was going to be unreasonably expensive and impractical. Hence, we worked with the Navy to put together a Live Fire Test program, which would result in a building-block approach starting early in the program, and gradually progress to the testing of the entire ship at levels that would not cause loss of the ship and its crew.

The LFT&E plan called for a series of vulnerability assessment reports to be made, then component/sub-system testing of various ship components and equipment, and modeling and simulation followed by realistic testing for penetration, shock and fire propagation, and suppression. Sub-scale models were also built and tested; a multi-floor hull section was built on land and tested for survivability to shock and blast. A foreign surrogate ship was even re-configured and tested (and eventually purposely sunk) to gather additional insights into the ship's vulnerability.

Flight I consisted of ships DDG 51 through DDG 71. Later in the LFT&E program, one of the ships in the DDG 51 class, DDG 53 (USS JOHN PAUL JONES), was taken to sea to conduct realistic underwater Full Ship Shock Tests (FSST) against the entire ship with its crew aboard and equipment functioning. Out of these tests came over 100 design and procedural changes due to the unexpected failure of certain systems to withstand the tests. Since crew were on board, the intensity of the blast had to be below levels at which the ship hull would be expected to fail.

One would ultimately have to ask, "How do you eventually test the ship's vulnerability to actual expected threat levels?" The answer is to couple all of the data learned in earlier LFT&E testing into a series of live fire events called Total Ship Survivability Tests or TSST. The Navy conducted TSST on the DDG 58 (USS LABOON). The ideas for these tests were born out of the LFT&E program office several years ago, and have now become an integral part of the way ship LFT&E is done. An AEGIS-class ship, complete with crew, went to sea with the understanding that they would experience a series of simulated attacks from various potential threat weapons. With little to no warning, the ship's leadership would sound an alarm indicating to the crew that they had just been "attacked" by a given threat. The ship's leadership would then immediately degrade the ship by cutting off power, fire protection, hydraulics, computers, doors, stairwells, simulate fire and smoke etc., based on what might occur given an actual attack, and learn how to fight and save the ship.

The Navy identified over 120 lessons learned from these trials performed under the DDG 51 Flight I LFT&E program, and used the knowledge gained to improve the ship's design and develop improved methods and procedures for combating damage. An automated battle damage display panel was developed to quickly identify and locate damaged systems and allow bridge personnel to take corrective action without loss of valuable time. A set of realistic training scenarios are being used to prepare DDG 51 crews for events such as those recently experienced by the USS COLE, another ship of this class. In fact, this recent tragic attack would most likely have been much more severe had the numerous survivability design improvements and tactics lessons learned in LFT&E not been applied.

LFT&E continues in DDG 51 Flight II/IIA beginning with DDG 73. TSST on DDG 79 (USS OSCAR AUSTIN) and FSST on DDG 81 (USS WINSTON S. CHURCHILL) are scheduled to occur in FY01. Modeling and simulation is also part of the LFT&E program, and will compliment FSST and TSST.

The V-22 and DDG 51 programs took advantage of opportunities afforded by their LFT&E programs. Knowledge gained from their respective Live Fire Test programs was used to make design changes that resulted in reduced system vulnerability and increased system survivability, changes that will certainly save lives and our combat systems.

These programs initiated contact with LFT&E early on in their programs. The Navy, in particular, decided to include susceptibility and vulnerability from the outset in its DDG 51 LFT&E program. They actively used the LFT&E program to gain valuable knowledge and insight, which was used to improve the ship design and develop enhanced battle damage control and repair methods. This exemplifies the goal of the Live Fire Test program.

The Live Fire Test Office conducts a multi-faceted program comprised of many coordinated efforts that have and continue to actively: (1) improve the survivability of fielded U.S. weapon systems, as well as those weapon systems undergoing acquisition; (2) reduce the vulnerability of fielded U.S. weapon systems as well as those weapon systems currently undergoing acquisition; and (3) increase the lethality of U.S. weapons. This includes survivability in both combat and peacetime environments. Crew casualty reduction is a major ongoing part in the Live Fire Test program. Specific accomplishments completed during the past year are presented in the following sections.

SPECIAL PROJECTS/INITIATIVES

MODELING AND SIMULATION FOCUS AREAS

The Secretary's theme to make more effective use of modeling and simulation opportunities is the guidance under which the LFT&E program has developed a modeling and simulation advocacy program. The LFT&E program supports the responsible use of modeling and simulation in several ways, ranging from the immediate application of models to acquisition programs, to mid-term and long-term model development initiatives. These include:

- **LFT&E PRE-TEST MODEL PREDICTIONS:** Requiring pre-shot predictions for every Live Fire and Joint Live Fire Program has added discipline to the T&E process. Comparing model predictions to test outcomes continues to provide valuable data to validate or improve our vulnerability/lethality models.

- **TILV PROGRAM:** A Target Interaction Lethality Vulnerability (TILV) program has been established to bring together technical experts from the military services and the Defense Threat Reduction Agency, to assure that their research addresses gaps in vulnerability and lethality technology without duplicating efforts. The TILV group is co-chaired by Deputy Director, Defense Research and Engineering (DDR&E) and the Deputy Director, Operational Test and Evaluation for Live Fire Test (DDOT&E/LFT), and is intended to help prioritize mid-term model development investments.

  The TILV Master Plan and Investment Strategy is a comprehensive effort to identify the technology investment areas providing the largest payoff to the Lethality/Vulnerability (L/V) community. This activity provides a forum for L/V experts from across the Services, and other DoD elements, to identify and prioritize areas where technology advances are needed in M&S. Service updates have been incorporated, and a revised plan will be available to support the Technology Area Review and Assessment process.

- **MEMORANDUM OF UNDERSTANDING (MOU) WITH THE DEPARTMENT OF ENERGY (DOE) ON M&S:** Long-term model improvements are the objective of initiatives established with the Department of Energy National Laboratories to utilize and evaluate physics-based computer models. Since the LFT&E program is "Test Data Rich" and DOE's Labs are "Model Rich," this effort has been mutually beneficial. These models have the potential to improve the understanding of system-level behavior by more accurately modeling fundamental component and material behavior. Through an agreement between the Director, OT&E, and the Assistant Secretary of Energy for Defense Programs, advanced computer codes of the Accelerated Strategic Computing Initiative are being used to help make pre-shot predictions for a wide variety of Live Fire Test and Joint Live Fire test opportunities. This effort has proven to be mutually beneficial for both organizations, and continues to grow in importance.

- **M&S SURVEY OF ACQUISITION PROGRAMS:** Recognizing the growing role that M&S is having in the T&E and acquisition activities of DoD, with the policy of the Department being one of simulation-based acquisition, we felt that it was important to understand how programs were being made: by whom, to whom, which models, and who pays for them/who owns them. IN FY99 DOT&E initiated, with the cooperation of the

Defense Modeling and Simulation Office and the Service Acquisition Executives, a Modeling and Simulation Survey to help answer these and other questions relative to M&S investments.

Twenty-two programs, including air, land, and sea platforms; weapons; and Command, Control Communications and Intelligence systems, from ACAT I-ACAT IV, were included in the study. The purpose of this study was to profile the investment in M&S software supporting Program Managers. This survey was completed during FY00 and extensively briefed to the DoD Pentagon leadership, including OSD and all Service Acquisition Executives. This has resulted in several specific changes relating to M&S to be included in acquisition policy.

- **MODELING AND SIMULATION PILOT PROJECT:** (As a follow-on to the Modeling and Simulation Survey discussed above.) In FY00 DOT&E initiated an M&S pilot project with each of the three Services. Each Service selected a candidate acquisition program for the pilot project. The purpose of this project is to develop an M&S methodology that more efficiently and effectively guides the use of M&S to support acquisition.

- **SAFETY AND SURVIVABILITY OF AIRCRAFT:** The Safety and Survivability of Aircraft Initiative (SSAI), now in its fourth year, is a collaborative M&S/Test effort between DOT&E/LFT&E, Sandia National Laboratories, and the Air Force Research Laboratory (formerly Wright Labs). The objective of SSAI is to critically assess our ability to predict the safety of aircraft in fire and blast events under flight conditions. The approach selected involves the use of computational models, well-instrumented experiments, and live fire tests. The complexity of fire scenarios and the requirement to address many different operational scenarios required a tiered modeling approach. This effort has shown that complex phenomena like fire cannot be properly understood by testing or modeling alone. The reconciliation of careful observations with detailed models does, however, provide an unprecedented capability to look inside the complexities of the fire environment. Opportunities to continue this work and extend it to the safety and survivability of ships and ground vehicles are being investigated.

- **OTHER M&S INITIATIVES:** Estimates of on-ground effects from chemical and biological agents released in a strategic or tactical missile intercept are the subjects of an LFT&E study concluded during FY00. There are many sources of uncertainty in the processes associated with missile intercept damage, agent dispersal and agent cloud formation, transport of that agent to the ground through complex weather and atmospheric conditions, and the subsequent impact on protected assets.

We are addressing the portions of the M&S spectrum that have the most significant impact on a particular problem of interest. We are working with the Defense Modeling and Simulation Office to help identify areas within the Conceptual Models of the Mission Space that are particularly important for relating data from Live Fire tests to assessments of compromised mission utility.

IMPROVEMENTS TO THE DoD 5000 SERIES

Fiscal Year 2000 saw the culmination of efforts initiated by DOT&E in July 1998. At that time, DOT&E proposed a forum to clarify LFT&E policy within DoD. Together with Army, Navy, and Air Force Test & Evaluation executives, we drafted new regulations consistent with Live Fire Test legislation, and reached consensus in late 1998. In 2000, these changes were incorporated into DoD

Regulation (DoD 5000.2-R). The changes: (1) clarify existing DOT&E policy requiring M&S predictions prior to Live Fire tests; (2) require evaluation of U.S. platform vulnerability to validated directed energy weapon threats; and (3) define LFT&E procedures and requirements for programs lacking a defined EMD or B-LRIP milestone.

LFT&E INTERNATIONAL MOU AGREEMENTS

Recognizing the importance of formal international cooperation and collaboration, this year the Live Fire Office initiated the development of a bi-lateral Memorandum of Understanding with several U.S. allied nations. The Live Fire Test Office is currently working on the development of these MOUs.

LIVE FIRE TESTING AND TRAINING (LFT&T) PROGRAM

The LFT&T Program directly supports another of the Secretary's T&E themes, that of bringing together the testing and training communities for their mutual benefit. It fosters the exchange of technology development initiatives and uses between the live fire test and training communities to better serve the ultimate customer—the warfighter. For the first time, the FY97 Defense Appropriation included funding to investigate alternative uses of simulation and training technology in support of Live Fire Testing and Evaluation. This initiative came to be known as the Live Fire Testing and Training program. Another goal of the program involves establishing partnerships between DoD and the civilian sector.

Congress has demonstrated growing support for this program each successive year since its inception, with funding for FY00 at its highest level yet. The LFT&T Program was initiated with $3 million in FY97, and continued with $4 million in FY98, followed by $5 million in FY99, and $7 million in FY00. Fiscal Year 2001 funding support for this initiative is larger yet. We have taken steps to fund this initiative through the LFT&E Program Element.

This program draws heavily on major U.S. simulation and training center expertise and is administered jointly by DOT&E along with the Services' simulation and training agencies. The program is managed by the LFT&T Senior Advisory Group (SAG), comprised of the commanders of the four Service training and simulation commands (STRICOM, NAWCTD, AFAMS, etc.) and chaired by DDOT&E/LFT.

The SAG meets several times per budget cycle to review proposals coming in from both government and industry, to select those most promising and oversee their progress and products, assuring that these efforts focus on readiness and also meet the needs of the testing and training communities. Several projects have "graduated" from the LFT&T program, and are already providing benefits to the warfighter.

The following projects were initiated under the LFT&T program and transitioned in FY00 to a follow-on user or sponsor:

- **COMBAT TRAUMA PATIENT SIMULATION:** This program leveraged existing commercial-off-the-shelf and government equipment to develop an integrated military medical simulation system for test and evaluation and training of medical personnel. The Combat Trauma Patient Simulation (CTPS) system provides the capability of simulating, replicating, and assessing battlefield injuries by type and category, monitoring the movement of casualties on the battlefield, capturing the time of patient diagnosis and treatment, and comparing interventions and outcomes at each military health care service delivery level. The CTPS system supports user assessments from field level to hospital trauma level. The CTPS program is a great success, receiving endorsements from the U.S. Army Surgeon General, the U.S. Air Force Surgeon General, the U.S. Army Medical Research Materiel Command, the National Guard Bureau, and the Special Operations Command. The National Guard is currently using CTPS to train first responders at Ft. Indiantown Gap, PA. The development of this system is continuing beyond the LFT&T Program. Congress provided additional funds in FY00 to expand the development of the system through FY01. The CTPS program brings live and virtual simulation to the medical training community, resulting in increased readiness of military medical personnel, and draws upon the user casualty prediction made from LFT&E.

- **SYNTHETIC ENVIRONMENT LIVE FIRE:** The objective of this project is to use a synthetic environment and simulation in a live fire test and training event to reduce the risk of test design flaws by allowing the test event to be conducted in the synthetic environment before actual physical execution, and to train both crew and individuals prior to actual live fire. The Bradley Fighting Vehicle was used as the candidate demonstrator. The Synthetic Environment Live Fire (SELF) project augmented existing test methodologies by replicating LFT&T in the synthetic environment. The SELF tests have clearly demonstrated that a high-fidelity training device is a capable test tool. Data are more easily accessed, thus providing a more flexible test infrastructure. Test officers using the SELF test have found the infrastructure useful for test preparation and design, pre-test exercises, and detailed data acquisition. Recently, the Army Program Manager for Combat Identification completed his Battlefield Combat Identification System (BCIS) IOT&E using test data obtained by testing the capabilities of the BCIS-equipped vehicles in this Close Combat Tactical Trainer (CCTT) device at Ft. Hood, TX. This entire test was conducted in a modeling and simulation environment on a CCTT system previously thought to be solely a training device, now a test and training device.

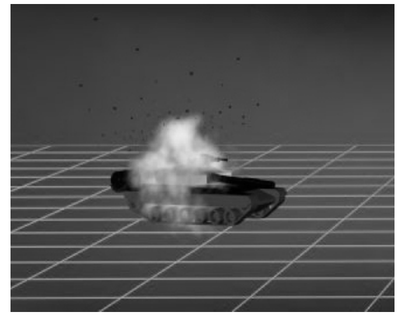
- **VULNERABILITY/LETHALITY SIMULATION ENHANCEMENTS:** This project focused on developing a methodology for improving damage assessments in tank-on-tank gunnery simulations used in the training, test, and analysis communities. The Probability of Kill (P_k)

methodology currently employed in these simulations does not provide for a detailed assessment of likely damage and resulting loss-of-function capability in simulated engagements. The goal of Vulnerability Lethality Simulation Enhancements (VLSE) was to find a way to replace the P_k methodology that would be acceptable in both communities and demonstrate the approach in one or more training system applications. The result has been development of a Degraded States Vulnerability Methodology (DSVM). The concept for DSVM was demonstrated with two current tank gunnery training simulations. Additional work accomplished under this project involved developing a methodology for new approaches to behavioral modeling of computer-generated forces—an important step for successful application of the degraded states methodology. The primary objective has been significant qualitative improvements in training and analysis of simulations so that we can avoid negative training (i.e., "train as we fight") and better evaluate system designs and tactics. The VLSE Project has directly resulted in a new initiative within the Army test/analysis community to further develop this methodology and expand its applications. The initial VLSE Project provided a platform and testbed for the Army Materiel Systems Analysis Agency's continued degraded states development efforts, and also supports the next generation of computer-generated forces (OneSAF) and other simulation developments.

The following projects are currently underway, comprising the FY00 LFT&T Program:

- **EFFECTIVENESS OF SMALL ARMS FIRE:** This project provides a re-configurable engineering tool, the Small Arms Simulator Testbed (SAST), for the small arms testing community which uses visual and physical modeling and simulation techniques to design, test, evaluate, and modify new small arms weapon concepts. Initiated as a project to support concept development and evaluation of the U.S. Army's Objective Individual Combat Weapon (OICW), the SAST has evolved into a tool that identifies critical technical/engineering issues through metrics associated with live fire test of future small arms. SAST also shows marked potential as a training aid of existing weapons. The testbed has resulted in more informed acquisition decisions by providing vital lethality metrics into small arms system design, thereby reducing the prototype development cycle time. Developmental issues such as error budgets, fire control systems, laser range finders, aiming, recoil effects, ballistics, probability of incapacitation, and weapon ergonomics are typical issues that can be examined by the SAST device. The SAST system has provided simulated live fire test data to the Army Research Laboratory and the Army Armament Research and Development Center to support development and testing for the OICW and the Force 21 Land Warrior Program. Efforts have yielded more than $10 million in direct savings to design and evaluation efforts. This project has the potential to greatly enhance the realism of anti-terrorism training simulation in urban settings for current and future weapon systems.

- **SIMULATION FOR PRODUCING REALISTIC MUNITIONS IMPACT FLASH EVENTS:** This project is exploiting live firings of anti-armor munitions against armor targets to collect impact signatures at various wavelengths to be used to guide development of synthetic image generation for use in trainers. These modeled results will be integrated into training simulator visual systems, providing gunners with an indication of what to expect from the impact flash effects resulting from engaging real targets, rather than the artificial image signatures now employed.



- **THREAT WARHEADS AND EFFECTS/BATTLE DAMAGE ASSESSMENT AND REPAIR (BDAR):** This is a joint U.S. Army and U.S. Air Force effort to develop a portable computer-based Battle Damage Assessment and Repair data storage/retrieval and training system supporting assessment and repair of battle damaged ground vehicles and aircraft. In support of Joint Live Fire (JLF) and Live Fire Test (LFT), BDAR engineers and technicians have been used to assess and repair test articles. Those technicians making the repairs, who are the actual military personnel that will be called upon to do repairs in combat, get exposure to realistic threat effects and damage on current and emerging vehicles, and quality hands-on experience. Though many of the BDAR technicians and engineers try to capture what they have learned and pass it on to their units, the information is often limited to a specific LFT program and distributed to the single PM restricting the potential training value. The problem was that no method existed to provide effective BDAR proficiency and threat warhead effects training, which provides realistic problem situations on current and emerging weapon systems, and constructive feedback. The objective of this project is to provide an efficient and effective method to capture, distribute, and use JLF and LFT information to enhance the proficiency of the combat maintainers and operators through realistic training across the board.

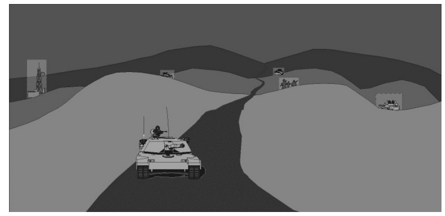
- **AUGMENTED REALITY-BASED FIRE FIGHTING FOR TOTAL SHIP SURVIVABILITY:** This is a proof-of-concept project supporting Total Ship Survivability Tests using Augmented Reality (AR) technologies to demonstrate the role of shipboard firefighters in fire damage assessment and fire extinguishing exercises. The objective of this project is to assess the feasibility of using current and future AR-based technologies in shipboard testing and training environments. Specifically, investigations into, and demonstrations of various display and tracking technologies, have been evaluated to demonstrate the capability to overlay realistic-looking fire, smoke, and extinguishing virtual images onto the real-world ship environment, including facilities, equipment, and other personnel. Augmented Reality promises to provide numerous benefits to the testing and training communities including improved realism, reduced operational

costs, dramatic safety improvements, elimination of combustion by-products, and elimination of environmental concerns.

- **DISMOUNTED INFANTRYMAN SURVIVABILITY AND LETHALITY TESTBED:** The Dismounted Infantryman Survivability and Lethality Testbed (DISALT) project leverages the existing high-fidelity SAST technology while developing and implementing new technology to provide a common framework to examine the complex interrelationships between man and multiple weapon systems. The specific objective of the DISALT system is to provide a validated multi-user small arms trainer infrastructure, allowing live fire testing and training communities to analyze, and subsequently optimize, the lethality and survivability of a fighting team. The DISALT system would further allow the small arms communities to more fully analyze and understand the synergistic effects of multiple weapon systems in a virtual collective exercise environment. In turn, the data collected during DISALT exercises would directly address the lethality and survivability of a team of soldiers, taking into account the synergy of multiple soldiers and weapon systems. This would ultimately lead to conclusions regarding optimization of weapon systems, tactics, mission effectiveness, and optimal training methods. In addition, performance metrics and methods of analysis would be developed to provide data reduction supporting the LFT&E and training communities.

- **ENHANCED RECOVERY OF AIRCREW FROM ACCELERATION-INDUCED LOSS OF CONSCIOUSNESS/ENHANCED ACCELERATION TRAINING:** One of the primary sources of loss of military high-performance aircraft and their crews results from their high-maneuverability. Acceleration, or gravitational-induced loss of consciousness (G-LOC) is one, if not the main, physiological threat to aircrew of high-performance aircraft. The objective of this task is to test several technologies that may be able to reduce the period of incapacitation occurring after a pilot experiences G-LOC. Investigation of these approaches holds the promise of discovering practical, simple, and cost-effective countermeasures capable of greatly reducing the mishap rate due to loss of consciousness in aircraft during peacetime, training, and combat situations. The first task under this project was to identify acceleration-induced aircrew issues in Navy and Air Force tactical aircraft. Additional tasks use Air Force centrifuges to test the efficacy of specific technological approaches to enhance recovery, including introduction of various physical stimuli including auditory, tactile, olfactory and visual sources, previous G-LOC training experiences, deflation rate of anti- G-suit, and reduced recovery acceleration levels. Reduction in the period of incapacitation will reduce the instances of aircraft and/or aircrew mishaps/losses due to G-LOC, enable the pilot to utilize the aircraft to its maximum performance potential, improve the mission and/or training experience, and enhance the overall utilization of the nation's warfighters and their aircraft.

- **INFRARED TARGETS TESTING AND TRAINING:** Training in the use of Infrared (IR) sensors requires targets that closely mimic the appearance of real targets in the IR spectrum. Approaches have been developed involving heated surfaces, but these are costly and sometimes not realistic. Initial explorations have proven a basic design for an IR projector based on Digital Light Processor (DLP) video projectors. The Infrared Targets For Testing and Training (IRT^3) project will adapt this technology to the live fire test and training arena. The IRT^3 project will develop an IR projection capability suitable for providing live fire targets for testing and training with IR systems in the 8-12 micron band. Under computer control, the projected images could appear and disappear, realistically simulating actual targets. The DLP technology will produce the full range of military targets on re-usable and re-newable (water based) projection screens. The use of projection technology will permit the isolation and protection of the expensive projector, only exposing a relatively inexpensive projection media to destructive fire. The projection media will be less costly than current targets, so the result will be improved realism and cost savings.



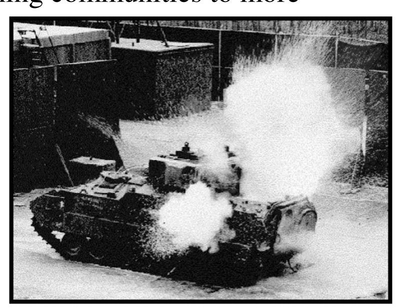
- **EXPLOITING LFT DATA TO IMPROVE WARFIGHTER SITUATIONAL AWARENESS IN COMBAT AND TRAINING:** Attack aircraft try to achieve first-pass attack success to increase mission survivability, while minimizing fratricide and collateral damage. Pilots and weapons systems officers need good situational awareness to make accurate and confident time-critical decisions. In training, this technology will familiarize pilots and weapons systems officers with the capabilities and effects of various weapons in a variety of attack scenarios. The technology will be designed for a specific host aircraft, but will be applicable to the aircraft of all three Services.

- **MISSILE WARNING SENSOR SIMULATOR:** The battlefield proliferation of light vehicle and man-portable air defense missiles is driving the development and deployment of a number of electro-optical missile warning receivers and associated countermeasures (flares, chaff, EW, etc.). The development of the Missile Warning Sensor Simulator (MWSS) was initiated to demonstrate that open-air testing of missile warning systems is possible without the expense of live firing large numbers of threat missiles. The objective of this project is to evaluate and enhance the capabilities of the MWSS and conduct a comprehensive verification and validation program. The MWSS is a transportable test and training tool designed to support operational evaluations of the AN/AAR-47 missile warning system that can be conducted with fully operational crews and aircraft performing realistic maneuvers and tactics. Earlier results from these tests have shown that the concept of an ultra violet laser stimulator is not only feasible, but also that the stimulator can highlight tactical considerations where the AN/AAR-47 is combined with other defensive systems to counter, defeat and/or destroy

infrared threat missiles. The enhanced MWSS will be a one-of-a-kind system, filling a void in infrared threat training, tactics development, and missile warning system testing, and will provide an improved means to assess aircraft survivability against infrared seeker missile threats. It will be deployable to most test ranges, can be operated in a safe manner with an ultra violet laser that is eye-safe at 13 meters, and will provide data at low cost with its two-person operation and capability to produce several tens of shots per hour—limited only by the operation of the aircraft against which it is deployed. With the completion of its development, the MWSS will be a flexible open-air testing, training, tactics development and evaluation tool that will have application for all the Services' aircraft employing missile warning systems.

- **VIRTUAL ENVIRONMENT SIMULATION FOR SHIPBOARD INCIDENT MANAGEMENT:** There is a requirement for both medical and non-medical personnel in the Navy to be trained and exercised in first response to major incidents involving damage to ship structures, systems, and personnel. Although ship interior spaces and systems have been modeled and represented in virtual environments in varying levels of detail, these have been modeled in undamaged states. And, although models have been developed to assess ship damage and survivability as a result of specific weapons effects, we are not aware of any efforts to accurately represent such damage in a virtual environment. This project will use ship design, off-the-shelf software, and the Virtual Environment Technology Testbed to develop a prototype shipboard virtual environment to train "first responders" in management of major casualty incidents. Similarly, by incorporating realistic damage modeling and representation, this project can serve as a platform for testing concepts in ship design for evaluating vulnerability, survivability, and recoverability.

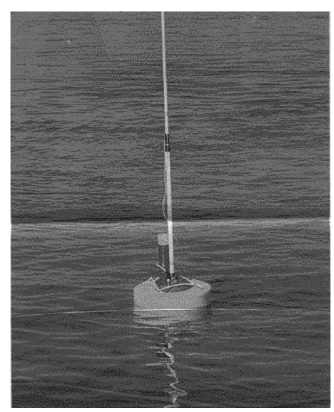
- **DEVELOPMENT AND IMPLEMENTATION OF NEW STANDARD VULNERABILITY/LETHALITY METRICS FOR FUTURE SIMULATIONS:** The objective of this project is to provide a sound methodology and set of vulnerability/lethality metrics to enable the combat simulation analytical and training communities to more accurately represent and analyze various aspects of combat capability. A set of test conditions will be modeled in several combat scenarios to examine the complex relationships between vulnerability fidelity (e.g. incorporation details of various loss of functions) and force effectiveness. In addition, new measures of effectiveness may be developed to provide a more accurate representation of battle outcomes. The proposed vulnerability metrics will substantially increase the fidelity and realism of vulnerability/lethality in simulations and have a cascading effect to many other areas, such as systems performance, human behavior representation, tactics, and force structure development. The proposed vulnerability metrics will provide mathematically accurate standard methodology to simulation developers from the analytical and training community to allow for high-fidelity modeling of vulnerability. Analytical studies involving performance issues, such as vulnerability reduction, weapon effectiveness, and logistics will directly benefit from improved vulnerability metrics. Higher fidelity



vulnerability modeling results in more representative visual and damage effects. Also, the analytical community will be able to better analyze and understand the synergistic effects of multiple impacts and the logistics support required for combat damage repair.

- **LIVE FIRE ADVANCED CONCEPTS:** Live team exercises for the dismounted soldier are complex and inherently dangerous. The Live Fire Advanced Concepts project explores the concept of how existing technologies and efforts can be leveraged to create a testbed that can be utilized for both live fire test and evaluation as well as collective and individual training. Although both a development and integration effort, this concept capitalizes on government, industry, and university investments. This project incorporates proven technologies to create a virtual world that simulates the dismounted soldier battlespace. This virtual world will be created by the utilization of the RealGuy™ system, which allows the soldier to maneuver throughout the battlefield utilizing a head-mounted display to view the terrain and both friendly and opposing forces. A model of a future weapon, such as the Objective Individual Combat Weapon, will be integrated into this virtual world, allowing the soldier to train, test, and develop new tactics, techniques and procedures. As the soldier traverses his area of operations, realism will be enhanced with the incorporation of 3-D audio and olfactory effects. This provides a suite of input (sight, sound, and smell) to the soldier to stimulate the human decision making process. Critical events and decisions will be recorded to facilitate the after-action review process and collect data on the lethality, survivability, and vulnerability of the weapon under evaluation.

- **VIRTUAL TARGET AND RANGE SYSTEM:** The Virtual Target and Range (VITAR) system is a portable, acoustic impact scoring system that is light-weight, compact, easily stored aboard ship, and deployed at suitable locations throughout the world's oceans. This project will initially provide a prototype system for conducting cost-effective live surface fire support exercises and supplementary training to Navy units. The final system will have the capability to determine the position of an impact and transmit the data back over-the-horizon to a system controller. The shipboard system controller will accurately display the impacts on real maps over any virtual terrain or target. The controller will have the capability to operate as a stand-alone system, or interfaced with shipboard systems to provide real-time feedback to the crew. While the VITAR system will not replace fixed ranges, it will allow individual ships to fire and score a wide selection of live fire training exercises almost anywhere at anytime. Ships being sent to combat areas can perform live fire tests of their guns to ensure their accuracy and operational effectiveness near their homeport. In addition, Long Range Weapon Systems such as the Advanced Gun System, the Extended Range Guided Munitions, and the Barrage round may not be tested to their full range capability due to test range limitations. The VITAR system will also allow full range testing at sea.



Live Fire Testing is unique in that, apart from actual combat, it is the only source of realistic combat vulnerability and lethality data, battle damage repair procedures, and estimates of user casualties.

This program takes this realistic data and combines it with training technologies and opportunities in a synergistic way. Efforts continue to make this program a funded part of the LFT&E Program Element.

REPLACEMENT OF HALONS AND OTHER OZONE-DEPLETING SUBSTANCES

Fire is, by far, the major source of U.S. combat casualties. Hence, fire detection and suppression is vital in the LFT&E of any platform. Weapons platforms use an array of ozone-depleting substances as fire and explosion suppressants. However, the Montreal Protocol now bans the production of these substances. Section 612 of the Clean Air Act, and Presidential Directives 12843 (1993) and 13148 (2000) call for the replacement of these substances where technically and economically feasible.

- **F-16:** Currently, the most Halon-emissive platform in the DoD inventory is the F-16 Falcon. TheF-16 uses Halon 1301 as a fuel tank explosion suppressant (so called inertant). It dumps 13 pounds of Halon 1301 into the atmosphere every time it is sent into a combat/bombing mission, whether the aircraft is hit or not.

  During FY98-99, the Air Force Research Laboratory, 46th Test Wing, and the Aeronautical Systems Center performed an extensive investigation on the search for the replacement for Halon 1301 as a fuel tank inertant for the F-16 Falcon.The RDT&E effort yielded the substance CF_3I, an effective, non ozone-depleting chemical, approved by the EPA for normally unoccupied areas, that performs equally with Halon 1301 and is a virtual drop-in replacement. The technology was thoroughly vetted and transitioned to the F-16 System Program Office with the approval of the Air Force Research Laboratory and the Aeronautical Systems Center. Airframe manufacturers also endorse the use of the agent, and Lockheed Martin performed a study to evaluate the retrofit costs for this application. CF_3I offers an additional benefit in its synthesis: CF_3I can be manufactured from Halon 1301 stocks, thus negating the need for destruction of the current stock of Halon 1301.

  During FY00, CF_3I has undergone extensive testing to assure its effectiveness. The Services have also been briefed on its effectiveness.

- **OTHER PLATFORMS:** Other weapons platforms also use Halon 1301 as a fire suppressant for engine compartments, dry bays, and Auxiliary Power Units (APUs), and there is an ongoing effort within DDR&E (Next Generation Program) to find suitable replacements for these applications as well. While CF_3I could, in principle, be used in most platforms where the application can be defined to be a normally unoccupied area—such as engine nacelles, dry bays, and APUs—test and evaluation still needs to be performed to validate laboratory and preliminary tests. Good candidates for the testing and possible use of CF_3I as retrofit or forward fits include cargo and fighter planes engine nacelles, dry bays, and APUs. The F-117 is considering the use of an On-Board Inert Gas Generating System (OBIGGS) for fuel tank inertion at considerable weight and space penalties. CF_3I may be considered a viable option considering the success of the F-16 program.

  During FY00, the LFT&E office has provided information to the Comanche PEO in their RDT&E efforts to find a Halon alternative to their engine nacelle application. The LFT&E office has assembled a panel of Army, Navy, Air Force, and EPA experts to provide feedback to the PEO. As to their selection process, LFT&E staff have also reviewed and provided improvements to test plans by the Navy for their F-14 fuel tank inertion tests, and to the Army for the Chinook CH-47 engine nacelle fire tests and F-117 OBIGGS.

CREW CASUALTY ASSESSMENT

The most important component of every live fire survivability test is an assessment of crew survivability—a determination of whether the crew or individual members of the crew could have performed physical tasks, completed the mission, and/or advanced to a safe position, subsequent to experiencing an incoming threat. During FY00, three crew casualty/survivability-related initiatives were conducted, over and above the system-specific LFT programs described throughout this report.

- **COMBINED TOXIC GAS MODEL:** The Combined Toxic Gas Model (CTGM) program was initiated in FY95 and completed during FY00. If the immediate injury vectors (e.g., blast, acceleration, and flash) of an incoming threat are survived (and they often are) and, although many fires may be extinguished in milliseconds, the post-shot, post-fire crew compartment may still present a hostile environment to the crew. Intense concentrations of toxic gases, mists, vapors, and particulates may fill the air for a period of time after the event. They arise, for example, from melted plastics, foam, and nylon, charred cloth, incompletely combusted ambient gases, pyrolysed fire suppressant, and burnt propellants. Escaping from an enclosure filled with these combustion products requires maintaining physical and mental abilities for a few critical minutes. The concentration exposures under these circumstances are sometimes extremely high, but very brief, and are conditions not encountered in normal human activities. Assessment of the hazard under these circumstances, and analysis of the toxicological profile produced from these multiple gas combinations, are necessary to evaluate human survival and the effectiveness of crew protection systems.

  For six years, the LFT&E Office funded the development of an immediate incapacitation model that incorporates complex physiochemical interactions between gases and tissues, and accommodates experimental data across animal species and humans. There were five phases to the CTGM design. They include: (1) a comprehensive literature search to identify all possible predictive models; (2) development of a preliminary model from all available information; (3) design of a working model; (4) empirical test and refinement of the model; and (5) employment of scaling factors and validation of the model in live fire cases.

  The derived mathematical model is based on a simplified representation of the inhalation, exhalation, and accumulation of toxic substances. It estimates the ventilation rate, accounting for species differences, activity level, and chemically induced physical response. The CTGM calculates the probability of immediate incapacitation as a function of time for any combination of seven gases: carbon monoxide, hydrogen cyanide, nitrogen dioxide, hydrogen chloride, acrolein, reduced oxygen, and carbon dioxide.

  The most notable report of this now completed effort is the discovery that the toxicity of a single gas is temporarily amplified when other toxic gases are also present. Hence, the toxicity models used up to FY00 must be significantly modified to reflect these findings.

- **GRAVITATIONAL LOSS OF CONSCIOUSNESS.** The second crew casualty related initiative, conducted in FY00, was to assess the G-LOC problem. Regardless of preventive measures taken to date, G-LOC remains a persistent and serious hazard in high-performance aircraft. From 1983-1996, the Air Force (the Service with the longest history of reporting G-LOC occurrences) experienced 24 class A mishaps and 18 fatalities as a result of G-LOC.

Anonymous surveys of combat pilots also report approximately 12 percent of Air Force and Navy pilots admit having experienced at least one G-LOC episode. Because temporary amnesia follows approximately 50 percent of G-LOC incidents, and, if not, victims may be reluctant to report it (even anonymously), the actual incidence of G-LOC is probably much higher than officially reported. Informal reports suggest that a majority of fighter aircrew (60-70 percent) have experienced some degree of serious G-induced incapacitation during their careers, an estimate consistent with the pervasiveness of the hazard, and a mind-set that accepts G-LOC as one of the many inherent risks in aviation.

- **AUTOMATIC GROUND COLLISION AVOIDANCE SYSTEM:** The third crew casualty related endeavor was initiated in FY99, and continued in FY00, and is being performed to also address the G-LOC problem. The effort is piggybacking on the automatic Ground Collision Avoidance System (GCAS) developed collaboratively for the F-16 and JAS39 aircraft by the U.S. and Swedish Air Forces respectively. This system continuously predicts the aircraft trajectory 10-15 seconds into the future. A digital terrain system data base is continually scanned around and in front of the aircraft, and the pilot selects a pre-set clearance plain over the terrain. If the future aircraft trajectory should penetrate the selected clearance plain, the automatic GCAS determines the appropriate time to initiate an automatic fly-up. If the pilot does not correct the trajectory, at five seconds prior to fly-up, a warning on the pilot's head-up display will appear. If the pilot still does not correct the aircraft trajectory, at zero seconds, an automatic roll to wings level five G fly-up recovery will occur. (The automatic recovery continues until the projected flight path clears the terrain feature of concern.)

Two demonstrations have been conducted so far to investigate the applicability of the automatic GCAS to the G-LOC problem. Three sorties replicating actual fatal G-LOC instances were successfully flown in FY00 utilizing the automatic GCAS incorporated within an F-16 aircraft.

JOINT LIVE FIRE PROGRAM

The JLF program was chartered by OSD in March 1984 to conduct Live Fire Testing of fielded U.S. and foreign air and ground weapons platforms and munitions. Programs selected under the original charter, and tested, include the AV-8B, AH-64, UH-60, F-16, F-15, F/A-18, MIG-23, MI-24 (HIND), T-62, M60A3, T-72, M1, M2/M3, and BMP vehicles. The aircraft systems tested under the JLF program (known as the JLF Air Systems Program) are managed by the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). Likewise, the JLF Ground Systems Program is managed by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME).

In the FY00 JLF Air Systems Program, vulnerability tests were conducted on the F-14 Tomcat, F-16 Fighting Falcon, CH-47D Chinook, and C-130E/H Hercules to gain insights into the vulnerability of fielded aircraft to threat munitions. Also during FY00, the JLF program conducted comparative tests of various fuel tank technologies that have been proposed for prevention of ullage fires and explosions exemplified in the TWA 800 accident. In addition, detailed plans were prepared for the second phase of vulnerability testing of the CH-47D main rotor blades and for testing the lethality of the U.S. PGU-28 20 mm projectiles against selected classified threat targets. The JLF program addressed the following programs in FY00.

- **SCUD-B MISSILE AND LAUNCHER TESTING:** Testing was conducted in November 1999 and in May 2000 against a SCUD-B Missile and Launcher at Eglin AFB, FL. The primary objective was to evaluate the vulnerability of the SCUD-B system to various U.S. inventory munitions. A secondary objective is to collect signature data before, during, and following test events to determine if signature changes might be detected and subsequently correlated to inflicted damage. The goal of this secondary objective is the development of battle damage indicator metrics that might improve battle damage assessment techniques and accuracy.

  This marks the first in a series of U.S. munitions tests that will be conducted against an operational SCUD-B missile mounted on its launcher (in the travel mode) to gather realistic data on actual threat targets recently made available for JLF testing. The first series of tests used BLU-97 bomblets, which are sub-munitions, delivered to the target area by the Joint Standoff Weapon System. M-74 bomblets, which are delivered to the target area by the Army Tactical Missile System, were tested in a May 2000 test series. Testing is expected to continue in FY01.

- **THREAT COMBAT VEHICLE TESTING:** Test planning was initiated on a threat land combat vehicle. A detailed test plan was started in FY00 and will be completed next fiscal year. Testing is expected to begin in spring 2001, with fielded U.S. threat weapons, and will include some threat weapons in development.

- **F-14 TOMCAT TESTING:** A JLF test was conducted during FY00 to determine whether an explosion in the external fuel tank could cause damage to the aircraft. Firing against an external tank mounted on an F-14 and filled with an explosive mixture of fuel vapors. Damage from the resulting explosion was limited to the tank itself. The results of this test suggest that it may not be necessary to incorporate explosion suppression features in the external tanks of this and similar aircraft since they appear to be sufficiently rugged to contain the damage.

- **F-16 MAN-PORTABLE AIR DEFENSE SYSTEMS (MANPADS) TESTING:** The Joint Live Fire program is addressing the issue of the Man Portable Air Defense Systems threat. The MANPADS threat is growing since stand-off weapons like the FIM92A *Stinger* and the Russian SA-7B *Grail* shoulder-fired, anti-aircraft missiles are increasingly available for purchase in the Mid-East, Western Asia, and Europe. Today MANPADS are found in nearly every nation on earth. As MANPADS become more readily available to terrorist groups and criminals, the potential for attacks against high value, low risk targets, such as commercial and military aircraft, may significantly increase.

  An SA-7 man-portable air defense missile was fired at a static F-16 Fighting Falcon target with the aircraft's engine running. The test was part of a broader series of tests to assess the vulnerability of U.S. aircraft to shoulder-fired MANPADS. The missile was fired from its launcher, flew free flight, guided itself to the target, and detonated on impact. Analysts, who are developing prediction/assessment modeling and simulation capabilities for MANPADS, are evaluating the damage to the test article. Previous free-flight tests with Stinger missiles launched against F-14 targets, (reported last year) have revealed unanticipated damage and raised questions regarding the unexpected damage mechanisms and weapon target interactions associated with this type of threat. The FY00 test against the F-16 was expected to be a more survivable engagement condition, replicating F/A-18 hits experienced during

Desert Storm. An initial assessment indicates the damage was less extensive than in the F-14 tests. The damage is being analyzed and compared with candidate models that will be upgraded based on these results. This test also served to demonstrate the ability to test MANPADS more realistically against aircraft with engines running.

Efforts to develop the rail-launch technique for foreign MANPADS also continued during FY00. The rail-launch technique would provide greater control over the impact location. In FY01 it is planned to duplicate the F-16 test conditions using a rail-launched SA-7. One objective of this planned test is to determine whether the rail-launch technique would affect the target damage by comparing the results with the free-flight test.

- **CH-47D TESTING:** The CH-47D Chinook JLF program addresses the planning, execution, and analysis of a series of ballistic tests to determine the vulnerability of the rotor blades and the rotor drive train system. The results of these tests will complement the ongoing LFT&E program for the CH-47F Improved Cargo Helicopter program, since the rotor blades and drive train are common to both variants. The rotor blade investigation consists of a three-phase series of ballistic tests of existing blade sections and whole rotor blades starting with static (no applied load), and progressing to quasi-static (applied static load) and dynamic (fully rotating blade system) tests. The rotor drive train test series consists of Phase 1 static component testing followed by Phase 2 dynamic testing.

  During FY00, the documentation of this JLF program was completed (Report No. JLF-TR-00-1) for the tests of the main rotor blade Phase1 static tests and the detailed planning for Phase 2. Phase 2 testing will determine the ballistic resistance of rotor blade sections under the influence of statically applied representative flight loads. The resulting damaged blades will then be structurally tested for damage growth, residual stiffness, and strength capabilities. Testing the damaged blades will require specialized facilities, and negotiations are underway with Boeing to support these tests. The rotor drive train portion of this program has been delayed due to lack of funds.

- **C-130E/H TESTING**: DOT&E designated the C-130J aircraft for LFT&E oversight in May 1995. DOT&E and the Assistant Secretary of the Air Force agreed, in March 1998, to establish a joint DOT&E/Air Force program that takes advantage of testing and evaluation under both the JLF program for the C-130E/H and the Air Force funded C-130J LFT&E program. The Air Force-funded program includes evaluation of dry bay fire, composite propeller blade vulnerability, engine and engine bay fire, and vulnerability to MANPADS. The JLF program addresses wing fuel tank vulnerability to hydrodynamic ram damage and mission abort vulnerability.

  In FY00, the JLF Program performed wing hydrodynamic ram evaluation tests on two C-130H left wing assemblies. The test series consisted of fourteen shots with several different threat projectiles fired into the wing fuel tanks at potentially critical locations. C-130 Battle Damage Assessment and Repair (BDAR) technicians from Robins AFB and a BDAR engineer were on site during the testing to assess damage and to repair the test article for subsequent shots. Detailed damage descriptions for each wing hydrodynamic ram shot were documented and sent to Lockheed Martin, the C-130 prime contractor, for analysis of post-shot residual strength and remaining flight capabilities. Results of these analyses will be published in FY01.

Planning for the C-130 mission abort vulnerability assessment under JLF will be initiated in FY01 and completed in FY02.

Several lessons learned can be drawn from this approach of leveraging JLF and LFT programs for evaluating system upgrades. For example, test articles for the aircraft upgrade LFT&E program can be economically constructed from some of the fielded models of the aircraft—if the changes are very small. For this program, realistic, production-representative test articles for LFT&E of the C-130J wing dry bay fire vulnerability were constructed from C-130H aircraft wings. In addition, the C-130H wing hydrodynamic ram damage testing conducted under JLF is applicable to both the fielded C-130 fleet and to the new C-130J aircraft. Finally, both JLF and LFT programs can benefit from active participation of on-sight BDAR personnel that quickly and economically repair test articles for subsequent shots. This approach also offers BDAR personnel the opportunity to observe realistic combat damage and receive training in assessment of damage inflicted by actual threat projectiles and application of aircraft battle damage repair techniques.

- **FUEL TANK FILLER JLF TESTS FOR FIRE/EXPLOSION MITIGATION:** The JLF Program planned and conducted two phases of a three-phase program during FY00 to evaluate six different technologies intended to protect aircraft and ground combat vehicle fuel tanks against fire and explosion when impacted by threat projectiles in the ullage, the vapor space above the fuel level. These technologies are based on various configurations of metal mesh or reticulated, open pore, foam to fill the fuel tank to prevent or suppress explosions or fires due to threat impact into the ullage. The tank filler materials are also designed to minimize fuel displacement and allow free-flow of fuel to the engine. Phase I was conducted with a heavy duty, re-usable tank wall simulator to obtain basic performance data. Phase II was conducted on an AH-1S Cobra helicopter to obtain data representative of realistic aircraft fuel tank installations. Phase III, to be completed in FY01, is planned to obtain data representative of actual ground combat vehicle fuel tank installations.

During Phase I, a 100-gallon fuel tank simulator was filled with the candidate protection technology. The tank was then filled with heated JP-8 fuel and drained to create an explosive ullage. A threat projectile was fired into the ullage to determine the effectiveness of the filler. Threat projectiles used in this test series were a high-explosive incendiary and an armor-piercing incendiary. Although final data reduction and evaluation of results are not yet complete, preliminary evaluations indicate that all of the fuel tank filler technologies significantly reduced the explosive overpressure compared to an unprotected baseline condition.

Phase II testing on installed AH-1S Cobra helicopter fuel tanks was done by installing the candidate fuel tank filler material, filling and draining the tank with JP-8, introducing JP-4S fuel vapor simulant to produce an explosive ullage, and firing the threat projectile into the ullage of the installed fuel tank. Phase II threats were the same as used in Phase I. Forward and aft fuel tanks were tested. Both fuel tanks are self-sealing. The forward tank is 190 gallons, and the aft is 92 gallons. As in the case of Phase I, complete data reduction and analysis of the results have not been completed. Preliminary evaluations indicate that all fuel tank filler technologies significantly reduced the explosive overpressure compared to that experienced when a threat projectile impacts the unprotected aircraft fuel tank.

- **PGU-28 LETHALITY JLF TESTS:** The U.S. 20 mm PGU-28/B SAPHEI (semi-armor piercing high explosive incendiary) projectile was developed in the mid 1980s as a replacement for the U.S. M-56A3 HEI projectile for use in the air-to-ground role due to its armor penetrating capability. Since it provided significant performance improvements in terms of drag, effective range, time of flight, and graze angle tolerance, it was decided the round would also be employed against air-to-air targets in gunnery scenarios. The PGU-28/B is the only projectile currently used by the Air Force and Navy for fixed-wing air-to-air combat. This projectile is fired from the M61A1 gun system that is utilized by the F-14, F-15, F-16, and F/A-18 aircraft. Current plans call for the use of the PGU-28/B with the M61A2 gun system on the F-22 aircraft. With the approximately 8,000,000 PGU-28/B rounds in the U.S. inventory, these tests will have a broad impact.

  While the PGU-28/B represents an improvement in aerodynamic performance, its lethality (damage capability given a hit) against actual aircraft targets has not been demonstrated. During FY00, the JLF program developed a plan to test the lethality of the PGU-28/B against selected targets, including a Soviet MIG-29 aircraft and Mil-24 Hind helicopter.

JTCG/AS

Fiscal Year 2000 marked the transition point for the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) from oversight by the Director, Test Systems Engineering and Evaluation (DTSE&E), USD(AT&L) to DOT&E/Live Fire Test, OSD. This transition was one of several actions recommended in the Defense Science Board’s T&E study and report of FY99, and helps bring together the Live Fire Test program’s efforts in survivability with other ongoing survivability activities.

The JTCG/AS is organized into three major sub-groups in order to focus their efforts in the areas of Vulnerability Reduction, Susceptibility Reduction, and Survivability Methodology. Past efforts have concentrated on these three distinct areas of survivability. Future efforts will start to focus on the synergistic benefits of addressing not only combat survivability, but aircraft safety as well. Also, since testing and modeling and simulation are integral parts of the scientific method, they will be focused to complement each other.

One of the most significant classes of threats to aircraft today is that of the MANPADS shoulder-launched, infrared, and radar-guided missiles. The JTCG/AS sponsored a national MANPADS workshop in FY00 to address this growing threat. Out of this came the culmination of the Joint Aircraft Survivability Against MANPADS study, a Joint Test and Evaluation Feasibility Study to generate test-validated joint tactics, techniques, and procedures. The Advanced Survivability Rotorcraft Project, initiated in FY00, is a first step in achieving rotorcraft survivability to MANPADS. Concurrently, the MANPADS Threat Characterization Project was also initiated to enable high-quality vulnerability assessments and risk characterization.

New and future aircraft will utilize weapons bays versus externally carried munitions. A weapons bay ablative protection “Proof of Concept” project is starting in FY01. It will determine the lowest weight combination of ablative and intumescent materials to protect the weapons bay against ballistic impacts. It will culminate in full-scale ballistic tests with live munitions.

JTCG/AS efforts in fire detection and suppression have been benefiting front line fighter aircraft for many years. These technologies have a great potential for re-use in commercial airliners, and will aid the Federal Aviation Administration (FAA) in achieving improved passenger safety. The JTCG/AS has conducted research and implemented engine computer software able to detect, identify, and mitigate engine damage. This technology has been developed and implemented on an F/A-18E/F F414 test engine. This type of technology research will also be used to enhance the Joint Strike Fighter engine development program.

The JTCG/AS has also completed the design, development, and test of a new cellular design, all composite, hydrodynamic ram tolerant, survivable fighter wing utilizing decoupled fuel cells. Wing and tail geometry's of the Joint Strike Fighter and Unmanned Combat Aerial Vehicle are appropriate for considering the cellular wing manufacturing approach, and the cellular co-cure technique may also be suitable for consideration in spacecraft structural designs.

The JTCG/AS jointly funded the Active Core Exhaust (ACE) project with the Air Force and the Defense Advanced Research Projects Agency to remove the core thrust reversers of a high by-pass engine, modifying the signature and heat generation of the engine exhaust. During summer 2000, ACE was tested on a C-17 engine test stand. Preliminary results indicate the design met its objectives; a flight test is being planned in FY01 to evaluate the full impact of the ACE design as installed on a C-17.

The JTCG/AS currently has four major methodology focus areas: (1) survivability model and simulation credibility; (2) transition to a new modeling architecture; (3) a new physics-based ballistic vulnerability simulation; and (4) an integrated survivability assessment process. The JTCG/AS has established the Joint Accreditation Support Activity to assess, improve, and document the credibility of approved survivability models available through the Survivability/Vulnerability Information Analysis Center (SURVIAC). The DDOT&E/LFT chairs the Senior Steering Group of SURVIAC.

The Joint Modeling and Simulation System (JMASS) is a new architecture being developed for creating new engagement-level models. The JTCG/AS is identifying and supporting ways to integrate JMASS models into simulations and leverage existing Joint Service infrastructures to address long-term distribution and configuration management of JMASS simulations.

The JTCG/AS, in cooperation with the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) and the Army Research Laboratory, continues efforts in FY00 to develop a new physics-based simulation to assess the vulnerability of a wide range of targets as well as the lethality of many types of munitions. The Advanced Joint Effectiveness Model (AJEM) is hoped to have the capability to calculate damage effects on a target system and determine the impact of that damage on the ability of the system to function.

The current method of aggregating results of engagement models, for use in mission and campaign simulations, is inadequate to make trade-offs between survivability enhancement features. The JTCG/AS is developing an Integrated Survivability Assessment approach that will allow for balanced and robust M&S across the survivability spectrum at the engagement mission and campaign levels.

JTCG/ME

Fiscal Year 2000 also marked the transition of the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) from the oversight by the Director, Test Systems Engineering and Evaluation (DTSE&E), USD(AT&L) to DOT&E/Live Fire Test, OSD. The JTCG/ME is the sole DoD organization chartered to publish joint Service-authenticated, non-nuclear weapons effectiveness data for use by the Department. These publications, called Joint Munitions Effectiveness Manuals (JMEMs), are the "how to" manuals for putting ordnance on target, and as such, directly impact combat readiness, effectiveness, and survivability. Weapons effectiveness data are available in both paper and electronic media (CD-ROMs, diskettes, and via classified computer networks). The JTCG/ME also develops and standardizes methodologies for evaluation of munitions effectiveness and maintains data bases for target vulnerability, munitions lethality, and weapon system accuracy.

Revisions to DoD 5000.2-R in FY00 now require that data be provided for the preparation of JMEMs data prior to the fielding of any major weapons platform or weapons system.

JMEMs are used by the warfighters in operational weaponeering, mission planning and training; the DoD, Joint, and Service planners in force-on-force modeling, mission area analysis, QDR, and requirements studies and weapon procurement planning (CBMR); and by the service acquisition community in performance assessment, analysis of alternatives, and survivability enhancement studies.

In FY00 the JTCG/ME executed the following work program:

- Completed conversion/updates of existing JMEMs and JTCG/ME Special Reports to CD-ROMs (i.e., JMEM Air-to-Surface Weaponeering System (JAWS) v2.1, Joint Anti-air Combat Effectiveness-Air Defense (J-ACE: AD) v1.0, JMEM/Surface-to-Surface Weaponeering Effectiveness System (JWES) v1.0, Special Operations Target Vulnerability and Weaponeering Manual v2.0, and Target Vulnerability Manual for JAWS v2.1, Joint Anti-air Combat Effectiveness-Air Superiority (J-ACE: AS) v2.0, Joint Anti-Air Combat Effectiveness-Air Defense (J-ACE: AD) v2.0, Joint Anti-air Combat Effectiveness-Ship Anti-air Warfare (J-ACE: Ship AAW) Prototype version, and JMEM/Surface-to-Surface Weaponeering Effectiveness System (JWES) v2.0.

- Distributed products, via the classified Internet, using the Joint Product and Information Access System (JPIAS) v1.0, (Books-on-line, Automated Products, Models, Tri-Service Data, and Support service).

- Expanded existing data bases to incorporate data for newly fielded weapons (i.e., Air-to-Surface Basic Manual-Revision 4 and Surface-to-Surface Direct/Indirect Fire).

- Addressed Target Vulnerability data generation and methodology improvements (e.g., buildings and content, rock penetration, agent release model, interdiction, fragment penetration equation standardization, and Operational Requirements-based Casualty Assessment (ORCA) extension).

- Continued the development of standardized models and methodology for Air-to-Surface, Surface-to-Surface, and Anti-air effectiveness calculations (i.e., Joint Anti-air Model

(JAAM) v2.0, delivery accuracy, building analysis, collateral damage, search/target acquisition, hardened targets, safe distances/risk to friendly troops, ship-to-ship gun effectiveness, dual stage warhead, directed energy weapons and Mean Area Effectiveness standardization).

- Conducted Configuration Management/Verification, Validation and Accreditation efforts on specific JTCG/ME models (i.e., Air Target Geometries, Blast Effectiveness Against Mobile Systems (BEAMS), ORCA, Penetration Curvilinear 3-D Model (PENCRV3D), Advanced Survivability Assessment Program (ASAP), Advanced Joint Effectiveness Model (AJEM), Modular Effectiveness/Vulnerability Assessment - Ground Fixed (MEVA-GF), Bridge Analysis System (BAS), Joint Service Endgame Model (JSEM), Joint Smart Weapons Module (JSWM), Joint Anti-air Model (JAAM), Simplified Artillery Effectiveness Model (ARTQUIK), Surface-to-Air Missile Site (SAMSITE), and Navy Gun Effectiveness Model (NGEM)).

- Together with JTCG/AS, continued to work the release of Advanced Joint Effectiveness Model v1.0 (with features including TBM Body-to-Body, Explosive Initiation, Hydrodynamic Ram, and Blast/Fragmentation Combined Effects) and the Joint Component Vulnerability Archive v1.0.

- Instituted an annual CINC data call to facilitate the development of a requirements driven program for FY01 and beyond.

In recognition of the vital importance of JMEMs, the JTCG/ME Program Objective Memorandum funding line was increased by $33.7 million over the Fiscal Year Defense Plan (FY02-07). This additional funding will reduce major methodology/data shortcomings, and ensure that JMEM data are available at Initial Operational Capability for most critical systems identified as highest priority by the operational CINCs. The funding will also increase weapons effectiveness data generation and documentation efforts to address highest priority CINC requirements, and help reduce CD-ROM update cycles to a maximum of fourteen months.

VULNERABILITY ASSESSMENT TO RADIO FREQUENCY THREATS

One of the roles of the LFT&E program is to assure that realistic testing is conducted using both current and future threats. This means ballistic and non-ballistic directed energy threats. There is a growing concern in some circles that as the U.S, becomes dependent upon computer-driven command and control, and as military digitization becomes the norm, that the possibility exists for a terrorist or rogue nation to seek to take advantage of this apparent vulnerability. We have supported the development of prototype High-Power Microwave (HPM) weapons and tests of these devices at DoD open-air ranges. As a result of these efforts, we now have some relevant equipment and experience with live fire testing of HPM weapons against military systems. However, additional program resources were needed to develop a more complete data base and experience in performing live fire tests using these non-traditional threats.

The U.S. Congress provided an initial increment of $4.0 million in FY99 to "expand threat vulnerability testing and evaluation to include the threat of Radio Frequency (RF) weapons." We prepared a broad agency announcement and subsequently published it in *Commerce Business Daily*. Twenty-eight responses (a mixture of submittals from both public and private sector vendors) were received in response to the announcement. A technical evaluation committee was convened, which subsequently evaluated the submitted proposals. In FY00, contracts were prepared and then awarded to 13 different companies and agencies. About one-quarter of the money was utilized for the development of a RF device, using components and technology from the open market.

The LFT&E Office conducted two RF vulnerability test series during FY00 at a DoD range. Both were outdoor, live fire, open-air tests oriented towards assessing the vulnerability of electronic-based systems representative of the U.S. commercial and military infrastructure to high-power ultra-wideband illumination under "operationally relevant" conditions.

Two different RF devices were employed; varying in waveform characteristics, rise time, pulse repetition frequency, burst length, and power levels. The targets tested included both a military weapon system and Commercial-Off-The-Shelf (COTS) technology. The COTS equipment was subdivided into two distinct sets: (1) industrial control and monitoring technology; and (2) medical equipment. The industrial control and monitoring technology included portable generators, power supplies, a physical security system, a fire monitoring and alarm system, a telephone-switching device, a baggage screening operator-assisted X-ray machine, a stand-alone emergency response system, and a ground-based navigation system.

Upsets and failures were more prevalent in the unhardened COTS equipment than in the hardened military weapon system, for which effects were minimal. The complete data is still being analyzed.

Plans for FY01 include: (1) conducting tests on two other military systems; (2) completion and testing of a new prototype ultra-wideband device built from readily available components (and with no access to classified target susceptibility data); (3) completion of calculations to relate transient electric fields inside a building to those incident on an exterior wall; (4) simulations of the effects of excess bit errors on the operability of the electronic units found in major weapons systems; and (5) completion of data analysis for tests already performed.